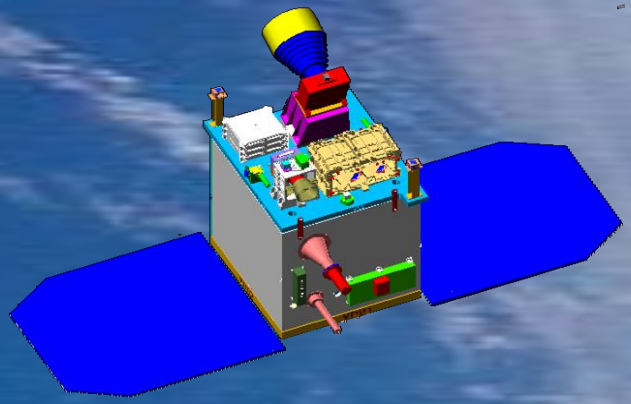


Systems Eng of Small Satellites and AI

Raghava Murthy V A Dantu
Director (Aerospace Research) Veltech R&D Institute , Chennai
Former Director (Small satellite Projects), ISRO
Secretary, SSSS

Points covered in talk

- System of Small Satellites
- Systems Eng of IMS-1
- Mission Aspects and demands
- Systems Engineering for constellations
- Capacity Building

Small Satellites :

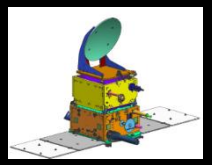
❖ MINIATURISATION WITH A MEANING

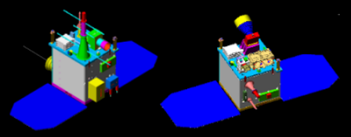
- Large > 2000kg
- Medium 1000kg -- <2000kg
- Small 500 kg -- <1000 kg
- Mini **100 kg -- < 500kg**
- Micro 10kg – <100kg
- Nano 1kg – <10kg
- Pico 100g -- < 1kg
- Femto 10g -- < 100g

Educational Satellites

Small Sats

SARAL 450 kg class Small sat





IMS-1, Youthsat..
100kg class Micro sats

Some Indian SS examples

* Rohini series ISRO
* HAMSAT (50Kg) ISRO

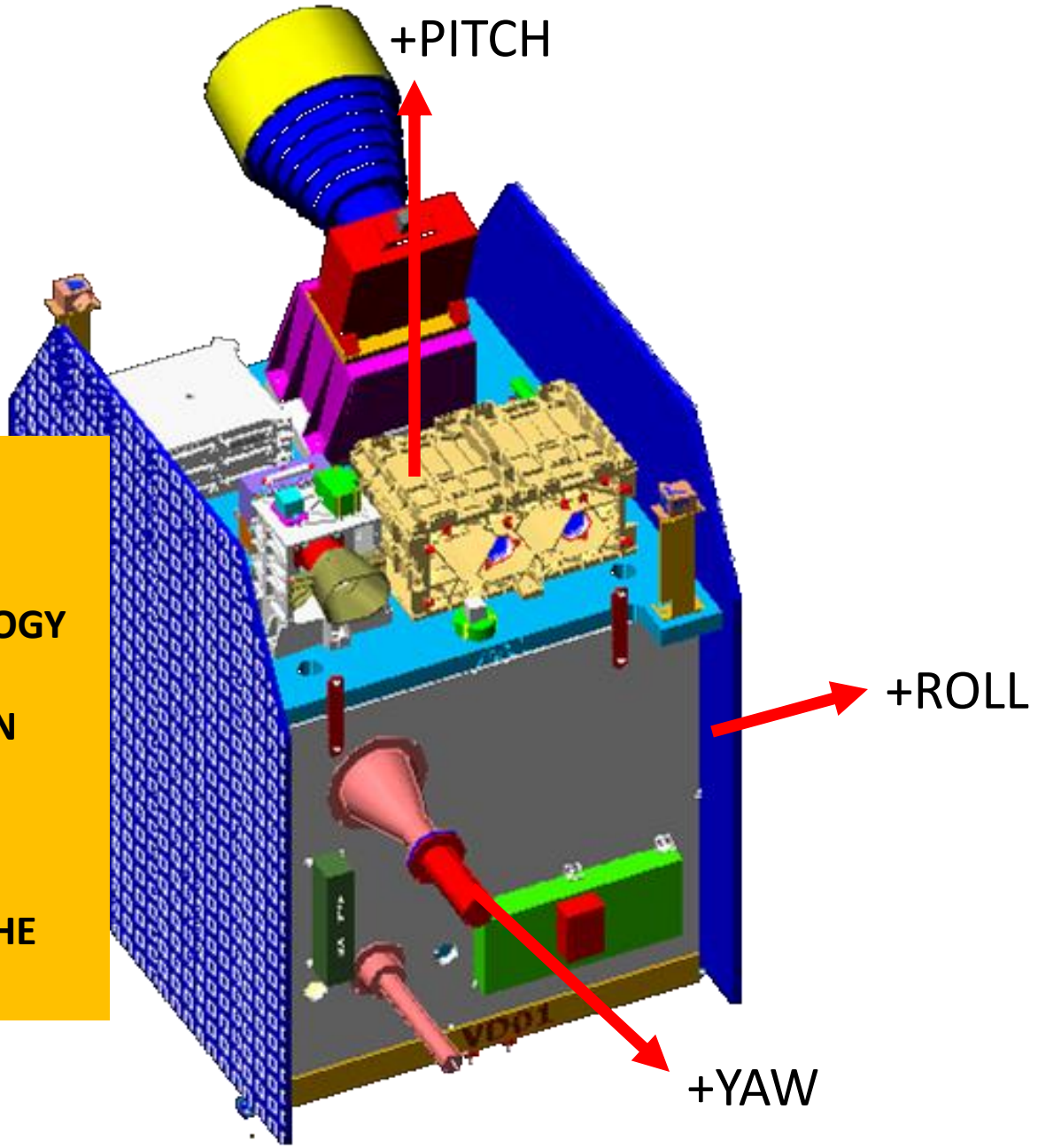
Educational satellites
ANUSAT(~50kg) ANNA U
STUDSAT(<1kg) 7 ENGG COLLAGES*
SRMSAT(<10kg) SRM U
JUGNU(3kg) IIT KANPUR
SWAYAM(1kg)
SATHYABAMASAT(1.5kg) SATHYABAM U
PISAT(5.25kg) PES U
PRATHAM(<10kg) IIT BOMBAY
NIUSAT(~15kg) NURUL ISLAM U
INS-1A/B/C (<5Kg) ISRO

Following definition of small satellites, <1000kg classes are CONSIDERED, which include operational, experimental, scientific, exploratory and educational satellites

- ❖ **FAILURES ARE POSITIVE FEEDBACK – LEARN AND CORRECT (ALL BIG SPACE ORGANISATIONS FOLLOWED THIS PATH)**
- ❖ **GOOD DOCUMENTATION IS ESSENTIAL – IT SHOWS WHERE TO CORRECT**

COURTESY : ISRO

- MISSION GOAL DEFINES SYSTEM
- GOAL CAN BE SOCIETAL APPLICATION, TECHNOLOGY DEVELOPMENT OR KNOWLEDGE EXPANSION
- SYSTEMS ENGG IS THE PROCESS TO MAKE THE SYSTEM
- NEVER LOSE SIGHT OF THE GOAL



IMS-1 AXES DEFINITION

COURTESY : ISRO

IMS-1 BUS SPECIFICATIONS & PAYLOAD CAPABILITY

SPACECRAFT

- 70 kg platform / 30 kg payload
- Orbit -SSO
- 500 – 1000 km orbit altitude
- Single System Configuration
- Life – 2 years

MAJOR PLATFORM SPECIFICATIONS

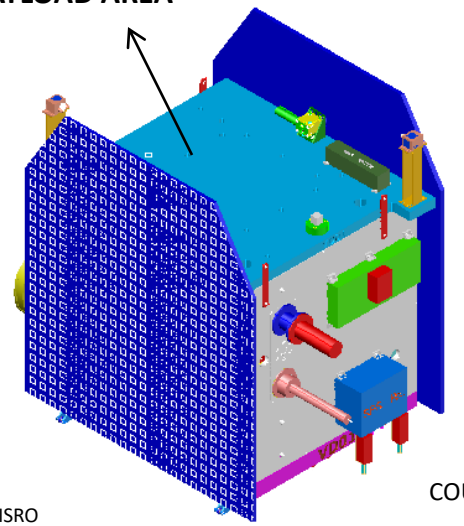
Dimension	552 x 600 x 600 mm
Mass	70 kg
Attitude Control	3-axis stabilized
Pointing Acc	0.1 deg
Drift rate	5.0 e^{-04} deg/sec
Science Data	S-Band @ 8 Mbps
TM Data	S-Band @ 4Kbps
TC Data	S-Band @ 100bps
Power Generated	230W
Platform Power	70W

PAYLOAD CAPABILITY

Mass	30Kg max
Volume	450 x 600 x 500
Interface	LVDS
Data Rate	10 Mbps max
Power	30W Continuous
	70W Duty Cycle
Power Bus	28 – 33V

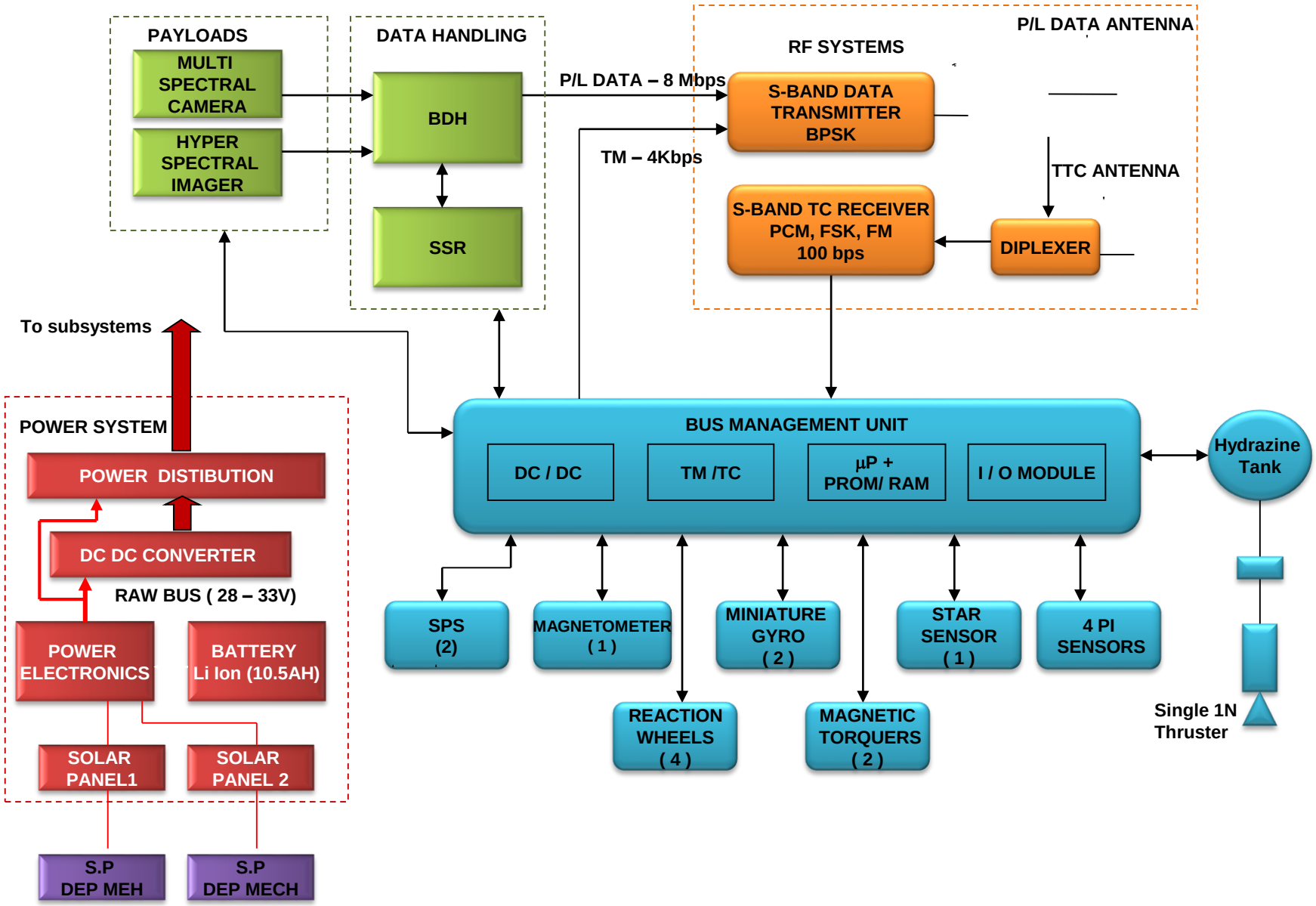
- Ocean and Atmospheric missions
- Earth Imaging Payloads
- Microwave remote sensing payloads
- Scientific Payloads

PAYLOAD AREA



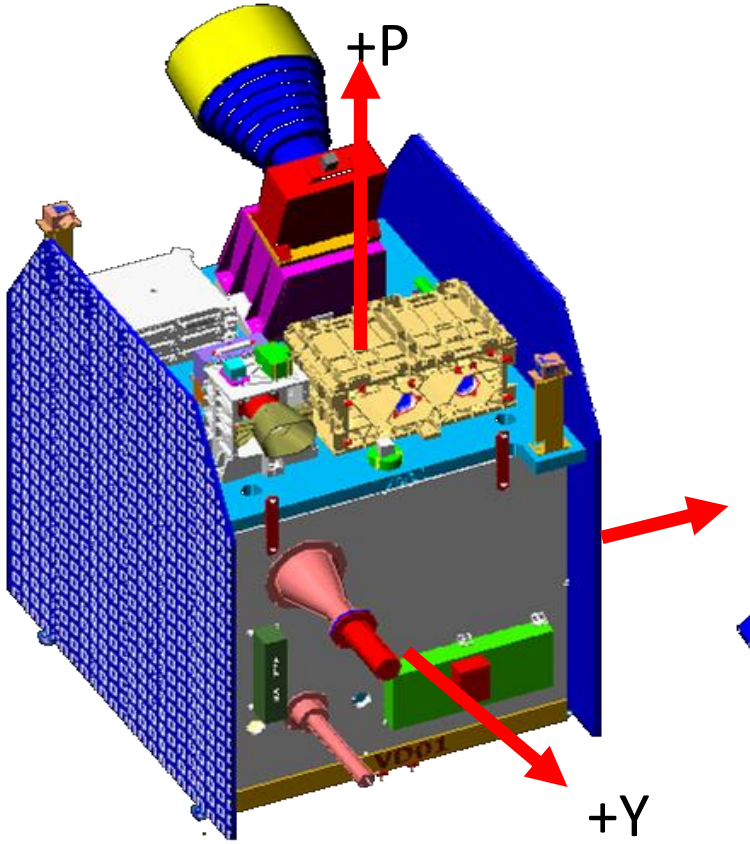
COURTESY : ISRO

IMS-1 CONFIGURATION

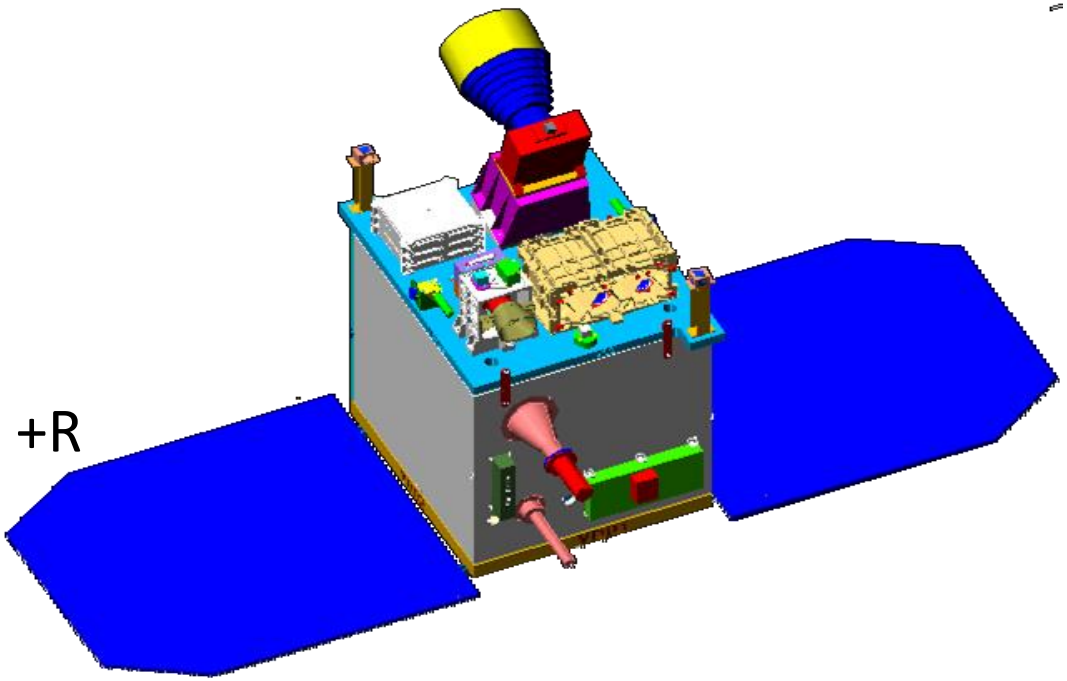


COURTESY : ISRO

IMS-1 STOWED VIEW

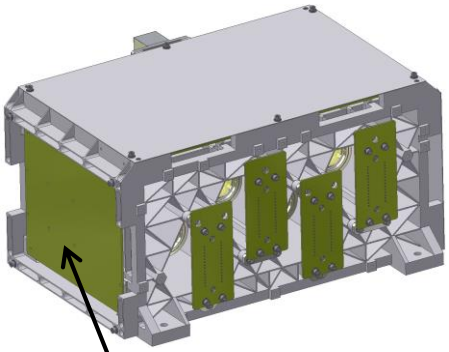


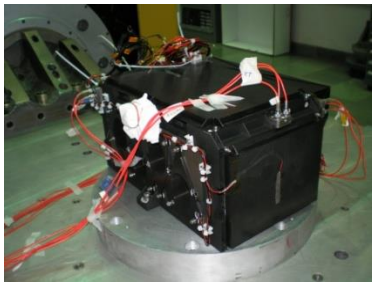
IMS-1 DEPLOYED VIEW



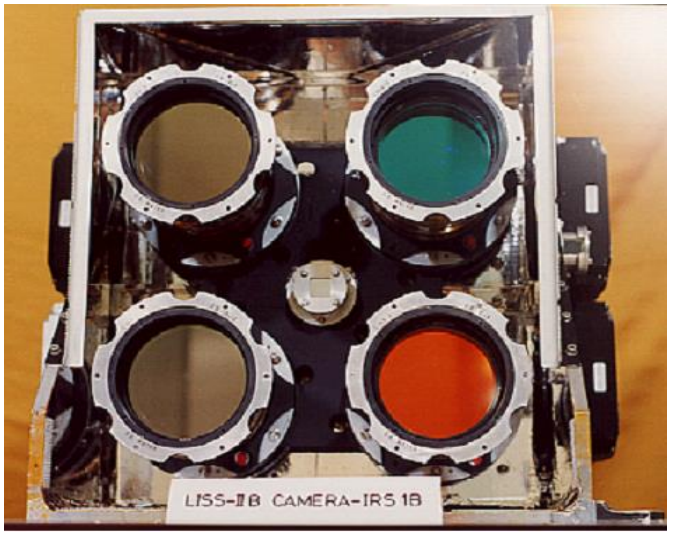
COURTESY : ISRO

PAYLOAD - MINIATURIZED MULTI SPECTRAL CAMERA





Mx : 300 x 148 x 227 mm / 5.5 Kg



LISS 2A/B – 162 Kg

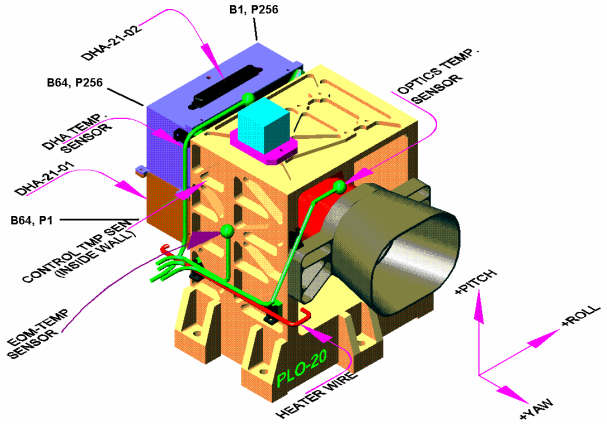
HIGHLIGHTS:

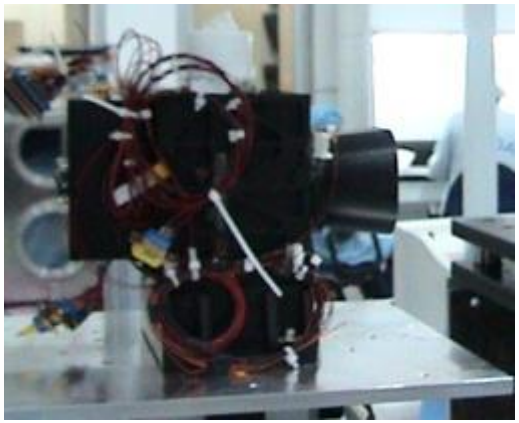
- Indigenous 4K Linear Array CCD, 7μ x 7μ pixel
- Modular Configuration
- Miniaturized Electronics using AFE, FPGA Micro D, MLB
- Miniaturized LENS assembly (0.27kg) compared to LISS2 (6.5kg)
- Usage of COTS AFE.
- Multi Linear Gain Implemented in FPGA
- Application – Natural resource monitoring

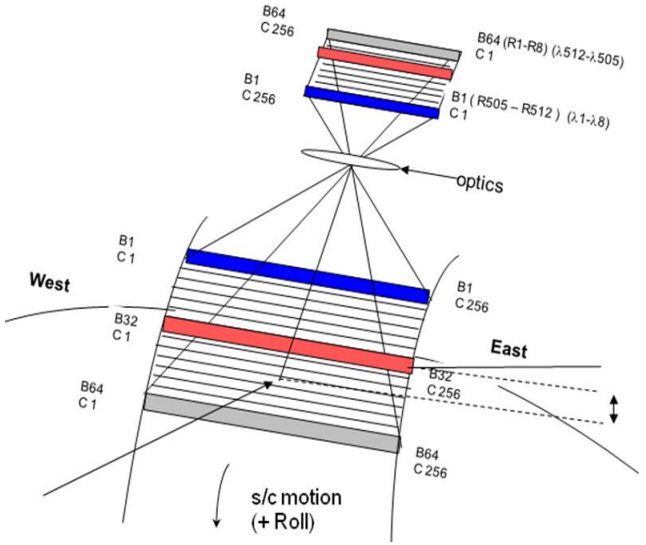
Multi Spectral camera Image - Rameswaram , Tamil Nadu

COURTESY : ISRO

PAYLOAD – ADVANCED HYPER SPECTRAL IMAGER





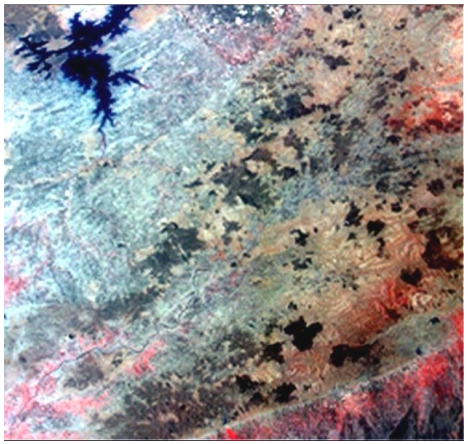


HySi Viewing Geometry

HIGHLIGHTS:

- **Detector: Area array (512 row x256 columns) Active Pixel technology; 12 bit digitizer**
- **Wedge Filter for spectral separation; sampling at 1nm interval and 8nm bandwidth**
- **Optics: Multi lens assembly**
- **512 bands processed to 64bands by binning**
- **Application –Ocean and atmosphere study with fine spectral resolution**

Hyper Spectral camera Image - Part of Madhya Pradesh



❖ MINIATURISATION WITH A MEANING

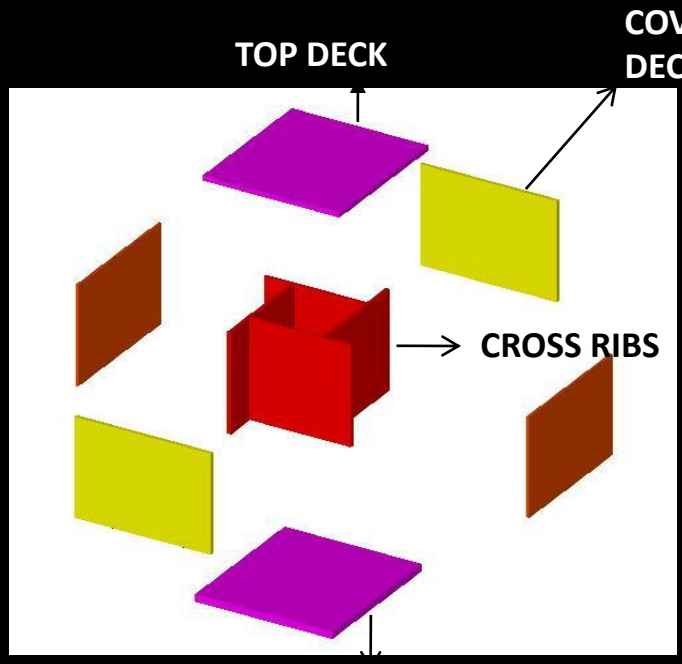
STRUCTURE

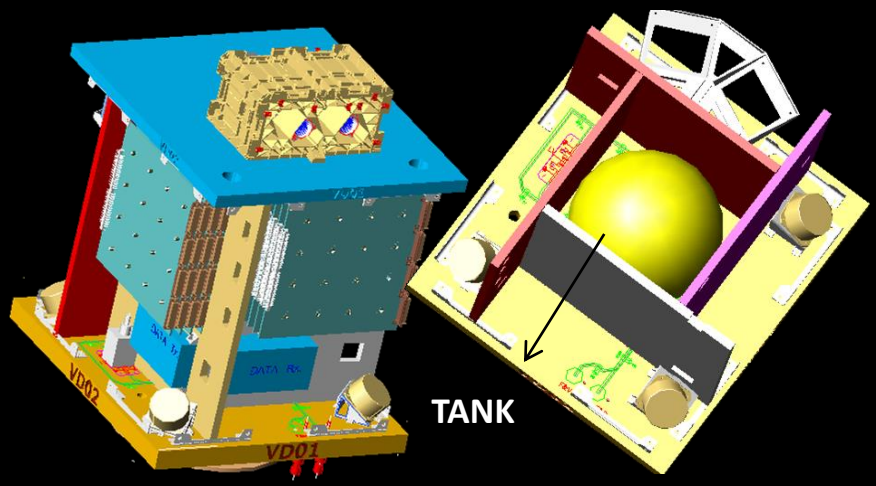
DESIGN

- Structure is built in a classical manner
- Aluminum honey comb sandwich based cuboid structure with a bottom deck, top deck and four cross ribs in a staggered fashion
- Four thin aluminum panels for covering deck
- Generates a central core to house tank and thruster elements

SALIENT FEATURES

- Direct Assembled Mode IST. (Systems mounted on Cross Ribs)
- No patch harness requirement
- Structure assembly time is less
- Provides easy unit access , flexible integration and checkout
- Reusable to maximum extent for other technology demonstration missions



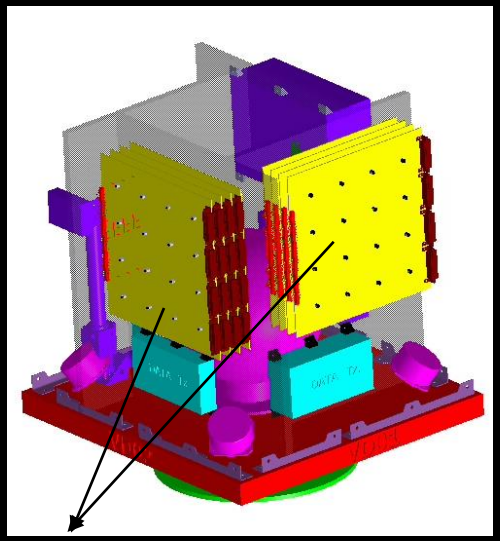


COURTESY : ISRO

- ❖ DESIGN STURDY TO MEET SURVIVAL REQ
- ❖ DESIGN AS A BUS WITH MODULARITY, ACESSABILITY AND ADOPTABILITY

❖ SIMPLICITY IS BEST ENG

NEW PACKAGING CONCEPT



PCB STACKS

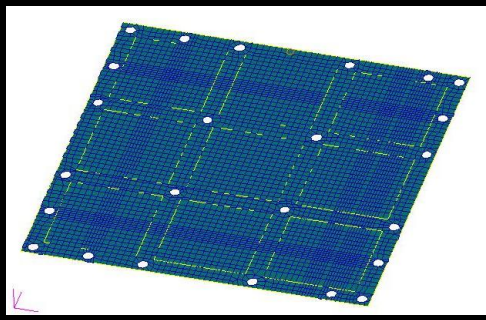
SYSTEM ON CARD REALIZATION

- Individual subsystem electronics are reduced to single PCB.
- Six Systems Realized on 12” x 12” PCB

STACK1: BMU, PSDC, WDE STACK2: IRU, BDH, SSR

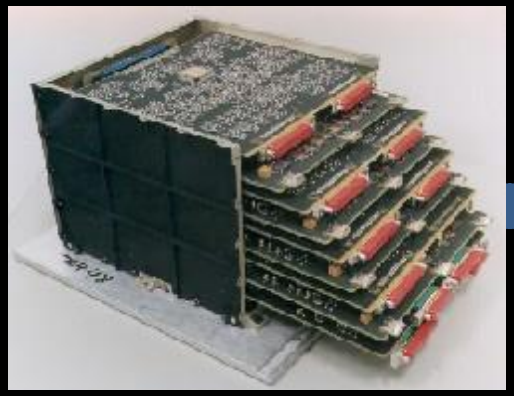
ADVANTAGES

- ***Optimal utilization of available area and volume at S/C level.***
- ***Reduction of mechanical hardware mass/subsystem.***
- ***Reduction of intra and inter package harness.***
- ***Standard packaging concept for small satellites.***
- ***Better thermal management at S/C level.***
- ***Reduction of integration and testing time.***
- ***Reduced no of components – Less failure / More reliability***



EXAMPLE: BMU MINIATURIZATION

SYSTEMS	CONVENTIONAL BMU	IMS BMU
No of PCBs	8 cards	1 card
MASS	12.5 kg	1.3 kg
PCB	8” X 9”	12” X 12”
POWER	20W	7W
H/W REALIZATION		3 MONTHS



CONVENTIONAL S/C BMU

IMS-1 BMU

CENTRALIZED POWER DISTRIBUTION SCHEME

REALIZATION HIGHLIGHTS

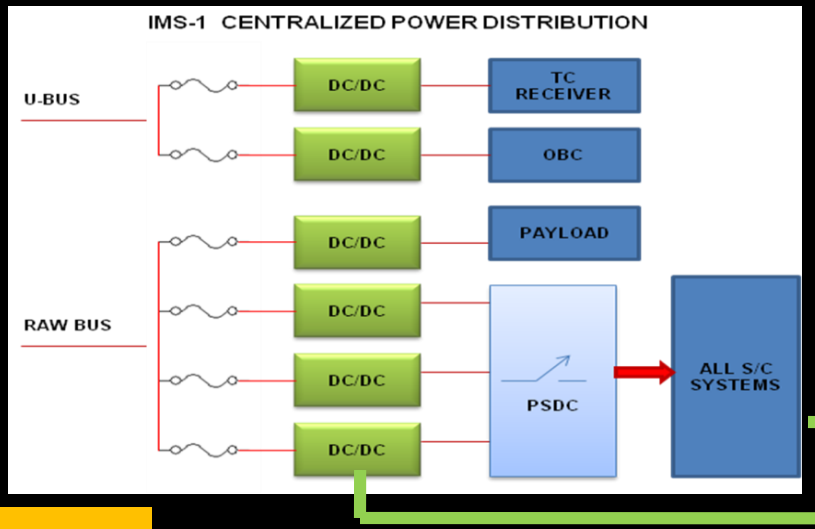
- *Shared DC DC Converters used to meet Platform voltage requirements*
  → Mass and Volume Saving at Spacecraft level

- *Switched Secondary voltages provided to Sub Systems*
  → Better real estate offered for Subsystems

- *Spacecraft Structure used as secondary return path*
  → Harness Reduction

ACHIEVEMENTS

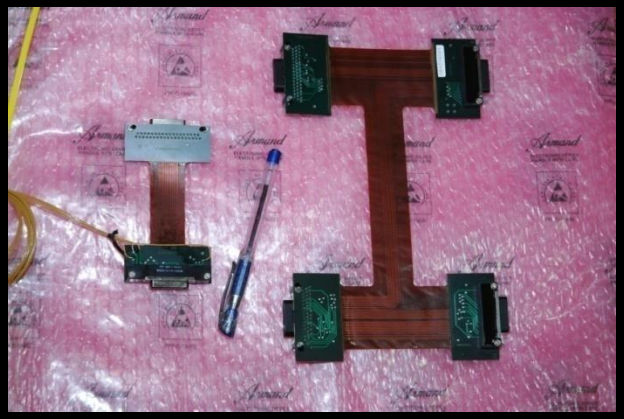
- *Only Five DC DC converters for platform*
  IRS - 50 approx.(M&R)
- *PSDC realized in single PCB (12" x 12")*
- *Resistance from any point to point on spacecraft*
  < 5 milliohms
  (IRS ~ 20 milliohms)
- *Harness reduction*



❖ DESIGN FOR LOW NOISE

COURTESY : ISRO

MICRO D CONNECTORS & FLEXI PCB



FLEXI PCB FOR HARNESS

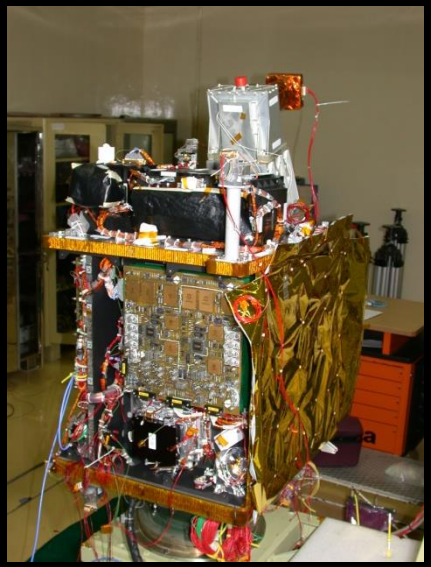
Implemented for the first time

- Reduces the no of connectors
- Reliability, Simplified Assembly
- Results in fewer wiring errors
- Repeatability and High Density.

MICRO D CONNECTORS FOR HARNESS

Implemented for the first time

- Less volume and weight
- 70% Micro D Connectors used



- Single harness for total spacecraft without any patch connectors
- Total harness has been formed on the harness jig itself

- ❖ USE MINIATURE COMPONENTS WITH QUALITY
- ❖ RELIABILITY IS RESPECTED AND IT PROTECTS GOAL

COURTESY : ISRO

DATA HANDLING SYSTEM – NEW TECHNOLOGIES

BDH

JPEG 2000 Compression

- Wavelet based Algorithm
- Improved low bit-rate compression performance (50% better than JPEG)
- Programmable compression ratio
- Improved lossless and lossy compression

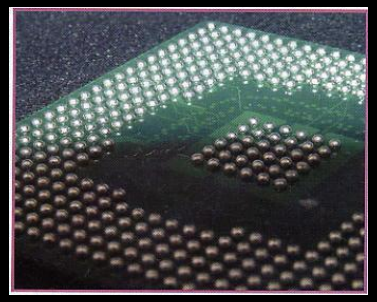
32 Mbps → **JPEG 2000 COMPRESSION (DWT) RATIO - 1 : 3.4** → 10.66 Mbps

RS Coding / Formatting

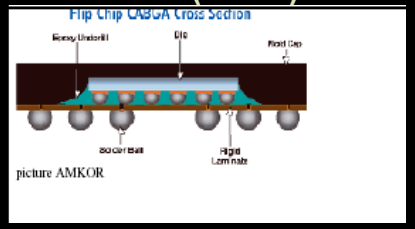
Use of BGA for the first time

Realized in a single 12” x 12” PCB (1kg)

Standardized electrical interface for payloads



ADV 202 (BGA)



SSR

Low Power, Volume and Mass (0.8kg)

Realized in a single 12” x 12” PCB

Use of SDRAMS for the first time

SSR (12”x12”, 0.8 kg)

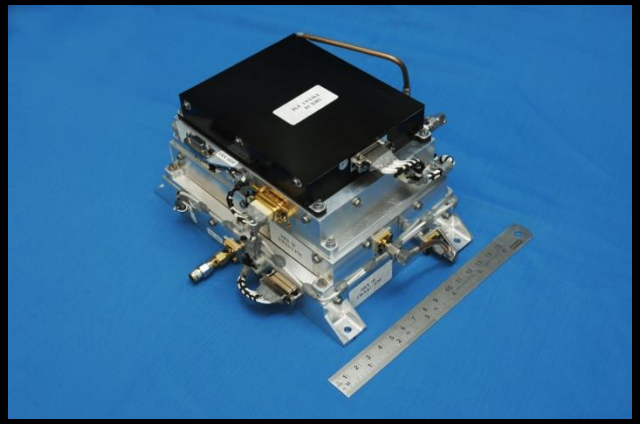
- HIGH THROUGHPUT WITH EXPANSION
- STADARDISATION WITH SCALING

COURTESY : ISRO

RF SYSTEMS – NEW TECHNOLOGIES

DIGITAL S-BAND RECEIVER

- **Digital Non Coherent Receiver**
- **DSP based FM/FSK demodulator**
- **Less volume , mass and power (1.5 kg)**
- **Programmable / Reconfigurable**
- **Highly suitable for micro satellites where space and power is premium**



❖ SS TECHNOLOGIES : GREAT CHALLENGES AND RESEARCH OPPORTUNITIES

SINGLE S-BAND TRANSMITTER FOR DATA / TM

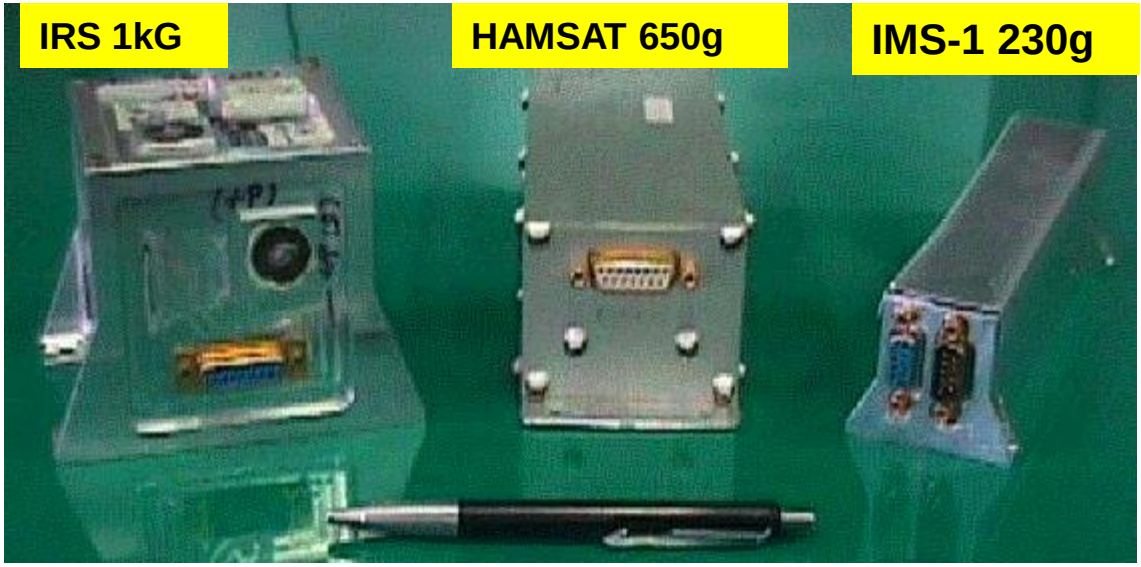
- **Single S-Band transmitter for Payload data/ TM**
- **Operates in high power / low power mode**
- **Direct modulation – PCM/BPSK**

MINIATURE SPS

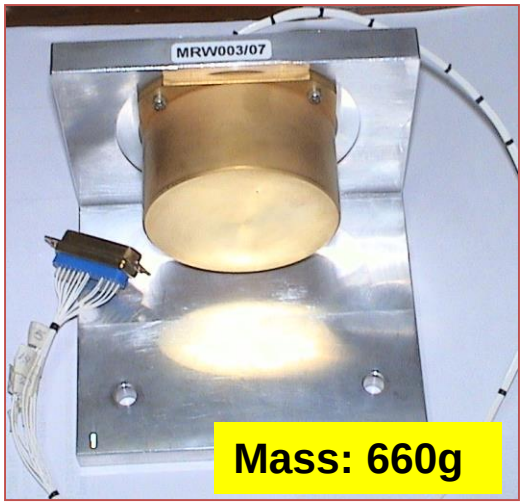
- **Miniature SPS from SSTL; In-house developed SPS Interface module**
- **Less volume, mass and power (1 kg, 1 W)**
- **Highly suitable for micro satellites where space and power is premium**

COURTESY : ISRO

AOCS – NEW TECHNOLOGIES

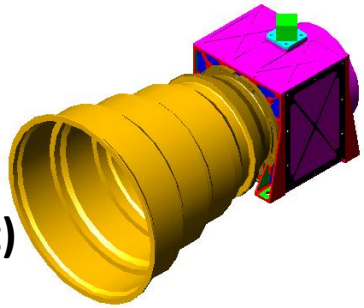


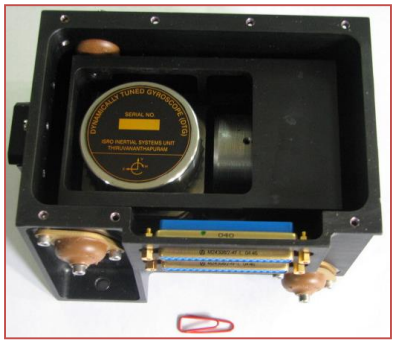
MINIATURE MAGENETOMETER (MEMS)



MICRO REACTION WHEELS

APS STAR SENSOR
(Under development)





Mass: 1.76 kg

MINIATURE GYRO

- EXPERIENCE GIVES BOOKS – BOOKS DON'T GIVE EXPERIENCE
- EXPERIENCE IS THE REAL KNOWLEDGE

COURTESY : ISRO

SOLAR PANEL DEPLOYMENT MECHANISM

HINGE MECHANISM with tape springs

Implemented for the first time

Provides the energy for solar panel deployment and acts as the latch on deployment of panels.

Advantages ….

- **Self drive & Self latch**
- **Less number of moving parts**
- **Less friction**
- **Low Mass (Tape spring -90g)**

HOLD DOWN AND RELEASE MECHANISM (Paraffin Actuator Based)

Implemented for the first time

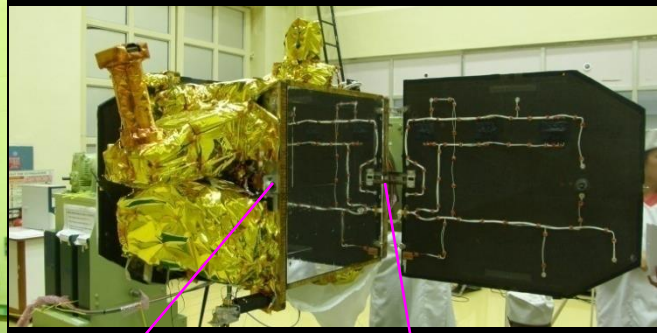
Retains the stowed panel integrity on ground, during launch and ensures a reliable release of the panels on command.

Advantages…

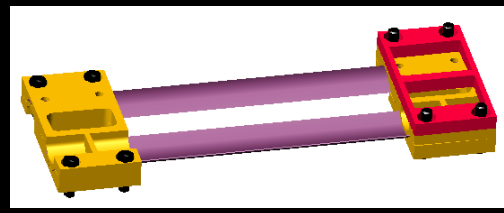
- **Non - explosive & Low source shock**
- **Reusable**
- **High reliability**
- **low mass (Paraffin actuator – 75 g)**

❖ NECESSITY IS MOTHER OF INVENTION

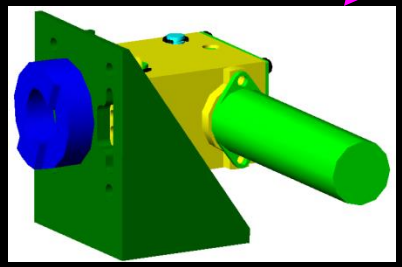
SOLAR PANEL DEPLOYED



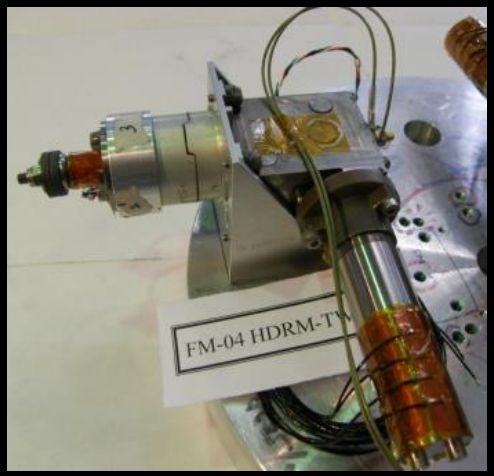
SOLAR PANELS STOWED

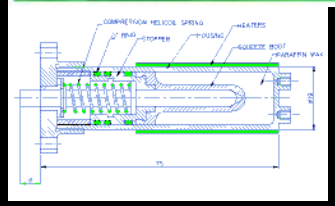


TAPE SPRING HINGE
(SELF DRIVE & LATCH TYPE)



HOLD DOWN & RELEASE MECHANISM





INDIGENOUS
PARAFFIN ACTUATOR

COURTESY : ISRO

COMPONENTS / QA PHILOSOPHY

COMPONENT PHILOSOPHY FOR EEE PARTS

- MIL grade parts preferred
- Industrial / COTS components usage allowed after Review
  Nearly 40 components used in IMS-1
- Usage of radiation-hardened components not mandatory AT ALL PLACES
- Shielding to be provided for parts if TID hardness is less than 10 k rad.

MATERIALS AND PROCESS CONTROL

- Usage of Commercial materials encouraged after Review
- Some of the new processes in IMS-1
  Wiring of Micro-D connectors
  Flexi PCB usage
  Mounting of the compression chip BGA in BDH

TEST AND EVALUATION

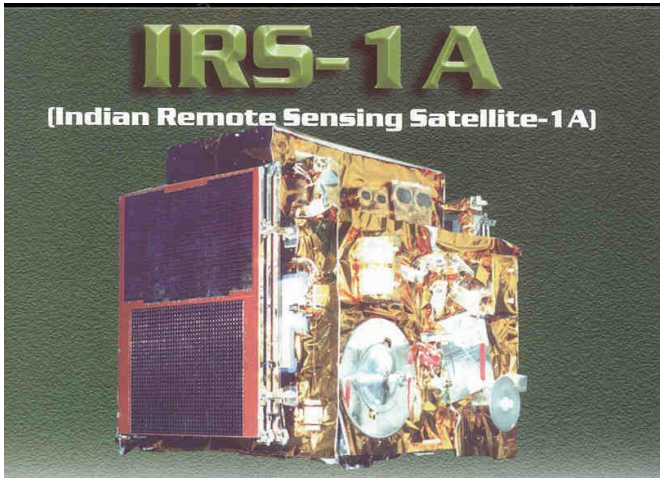
- Simple Non conformance control methods
- Responsibility of unit-level testing transferred to the subsystem manager

REALIZATION PHILOSOPHY

- Single Model Philosophy except for new development systems

❖ NANO SATS ENTERING OPERATIONAL AREA REQUIRES STRONG QUALITY ASSURANCE

COURTESY : ISRO



IRS 1A/1B

Mass –975 Kg
Power – 600W
***Payloads* – LISS –1,LISS –2A, LISS-2B**

EXTENT OF MINIATURIZATION

- GO AHEAD AGAINST ODDS – THESE ARE NATURAL FOR INVENTIONS

SUB-SYSTEMS	WEIGHT(Kg)	
	IRS	IMS-1
PAYLOAD	160	5.5
POWER EL	11	3
BMU	12.7	1.5
SSR	9.5 (60GB)	0.9 (16GB)
BDH	21	0.9
STAR SENSOR	5	3
WHEELS (4 NO.)	20(5NMS)	3.2(0.36NMS)
WDE	3	1.5
GYRO UNIT	14.5	1.8
GYRO ELE		1.5
RF RECEIVER	4	1.5
MECHANISMS	11	1

Mass – 83 Kg
Power – 80W
Payloads – Multi Spectral Camera
Hyper Spectral Camera

IMS-1

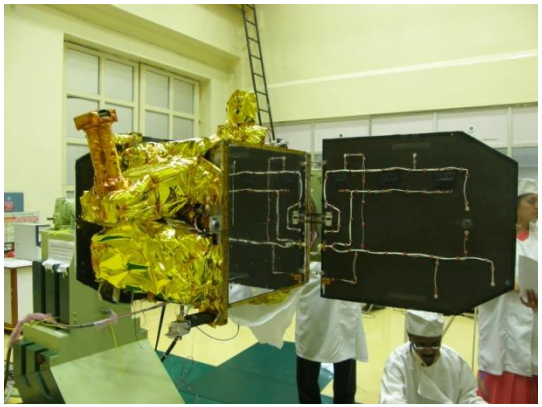
COURTESY : ISRO

❖ AVOIDING TESTS ENSURES RISK

IMS-1 - GLIMPSES

IMS-1 - IN CLEAN ROOM

IMS-1 - UNDER VIBRATION



SOLAR PANEL DEPLOYMENT TEST

SHIPPING TO SHAR

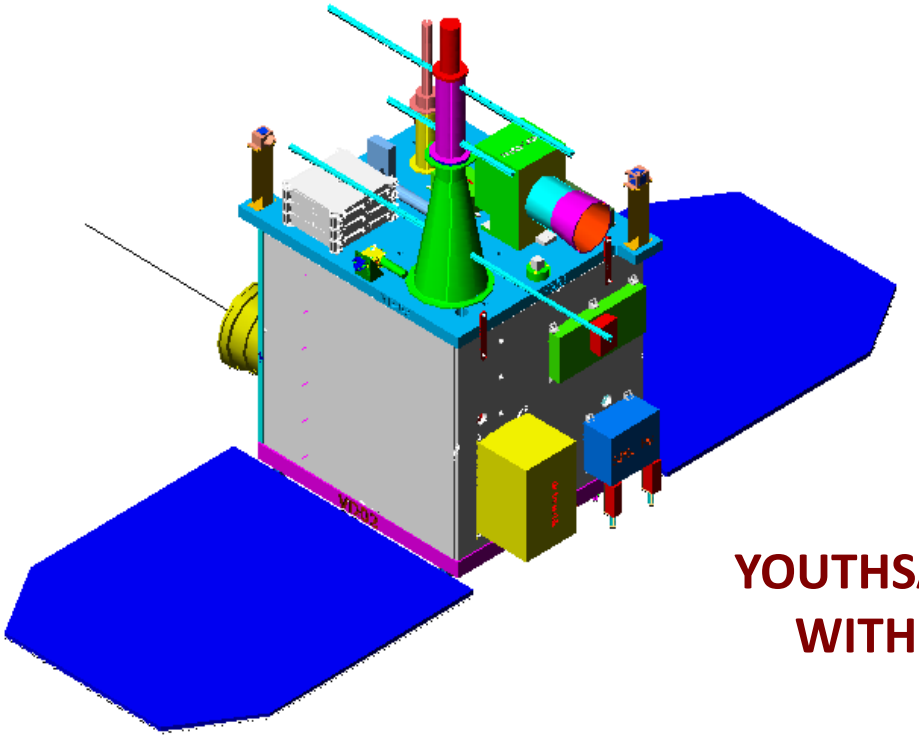
MATED WITH LAUNCH VEHIC__

PSLV C9 LIFT OFF

❖ SATELLITES NEED TO BE IN ORBIT -- OTHERWISE IT IS A LAB MODEL

❖ FIX LAUNCHER(S) BEFORE STARTING DESIGN

COURTESY : ISRO



YOUTHSAT -- SECOND MISSION ON IMS-1 BUS WITH ATMOSPHERIC AND IONOSPHERIC OBSERVATION PAYLOADS.
FIRST INDIAN SATELLITE WITH PROFILE PROGRAMMING ONBOARD

- A SATELLITE BUS MEETS DIFFERENT MISSIONS WITH LEAST ADJUSTMENTS
- **SATELLITE BUSSES** ARE USEFUL FOR CONSTELLATIONS

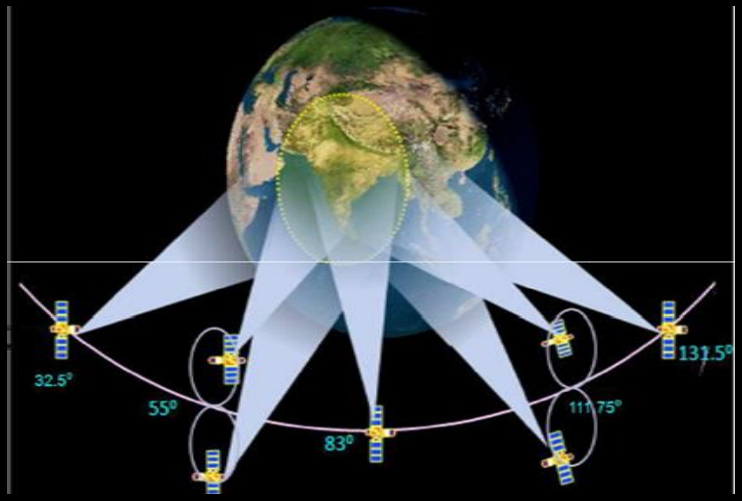
Increasing Application Demands

Application	Resolution	Bands	Repetevity
Infrastructure building / Town & Urban Planning and governance	0.5 to 1m	PAN	Daily to 1week
Agriculture • Crop monitoring • Crop yield estimation	5 (1m) To 50 mtrs	VIS – NIR – SWIR (Hper spec , Microwave/SAR)	2 to 30 days
Forestry	50 (1 m) – 150 mtrs	VIS-NIR-SWIR (Hper spec , Microwave) TIR (forest fire monitoring)	Few months 1 – 5 days (Hourly)
Water resources Oceanography	20 – 100 mtrs 100 – 1000 mtrs	NIR VIS-NIR-TIR MW	Few months Daily - weekly
Disaster management	< 10 mtrs	VIS-NIR SAR	Few hours

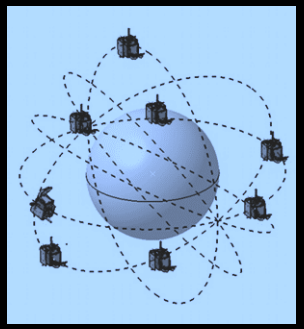
❖ EVERYWHERE ALL THE TIME MONITORING --- GREATEST DEMAND

Constellations

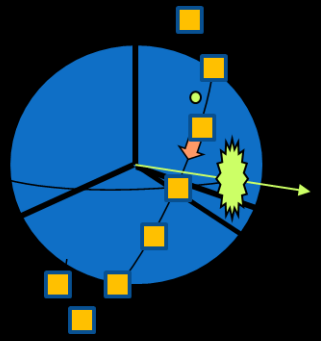
- **A satellite CONSTELLATION MISSION is number of satellites in orbit(s) to deliver an identified task or service with supporting ground infrastructure**



IRNSS



GPS



Remote Sensing satellites

SINGLE SATELLITE SYSTEM

MISSION ELEMENTS

SATELLITE SEGMENT

- PAYLOAD1
- PAYLOAD2
- PAYLOAD2
- PAYLOAD3

SATELLITE BUILDING, TESTING AND QUALIFICATION : ~ 50 people

GROUND SEGMENT

- DATA PROCESSING AND PRODUCT DELIVERY – M1
- DATA PROCESSING AND PRODUCT DELIVERY – M2
- DATA PROCESSING AND PRODUCT DELIVERY – M3
- DATA PROCESSING AND PRODUCT DELIVERY – M4

SATELLITE TRACKING AND CONTROL : 8

USER SEGMENT

- USERS– M1
- USERS– M1
- USERS– M1
- USERS– M1

SATELLITE CONSTELLATION SYSTEMS

- CONSTELLATIONS ARE WITH ALL AND FOR ALL

MISSION ELEMENTS

SATELLITE SEGMENT	GROUND SEGMENT	USER SEGMENT
CONST WITH PAYLOAD1 : SAT BTQ : Pple C1 x N1	DATA PROCESSING AND PRODUCT DELIVERY – M1 Const control : C1 x N2	USERS– M1
CONST WITH PAYLOAD2 SAT BTQ : Pple C2 x N3	DATA PROCESSING AND PRODUCT DELIVERY – M2 Const control : C2 x N4	USERS– M1
CONST WITH PAYLOAD3 SAT BTQ : Pple C3 x N5	DATA PROCESSING AND PRODUCT DELIVERY – M3 Const control : C3 x N6	USERS– M1
CONST WITH PAYLOAD4 SAT BTQ : Pple C4 x N6	DATA PROCESSING AND PRODUCT DELIVERY – M4 Const control : C4 x N8	USERS– M1

Redundancy aspects

	Medium / Small /Mini	Micro	Nano/Pico
Payload(s)	S	S	S
Structure	NA	NA	NA
Power	R	RL	S
TTC	RL	R	S
Data Handling	R	R	S
AOCS	R	R	S (RH components)
Sensors	R	RL	S
Torquers	RL	S	S
Prop	RL	S	S/NA
Thermal	RL	S	S
Mechaniasms	RL	S	S
S : Single sys, R : Redundant , RL : Limited Redundancy,			

Artificial Intelligence Requirements and Oportunities in Small Satellites in constellation

- For Satellite maintenance
- Payload Operations
- Onboard data processing product delivery
- Resource sharing
- Intersatellite communications
- Contingency and survival.

Constellations

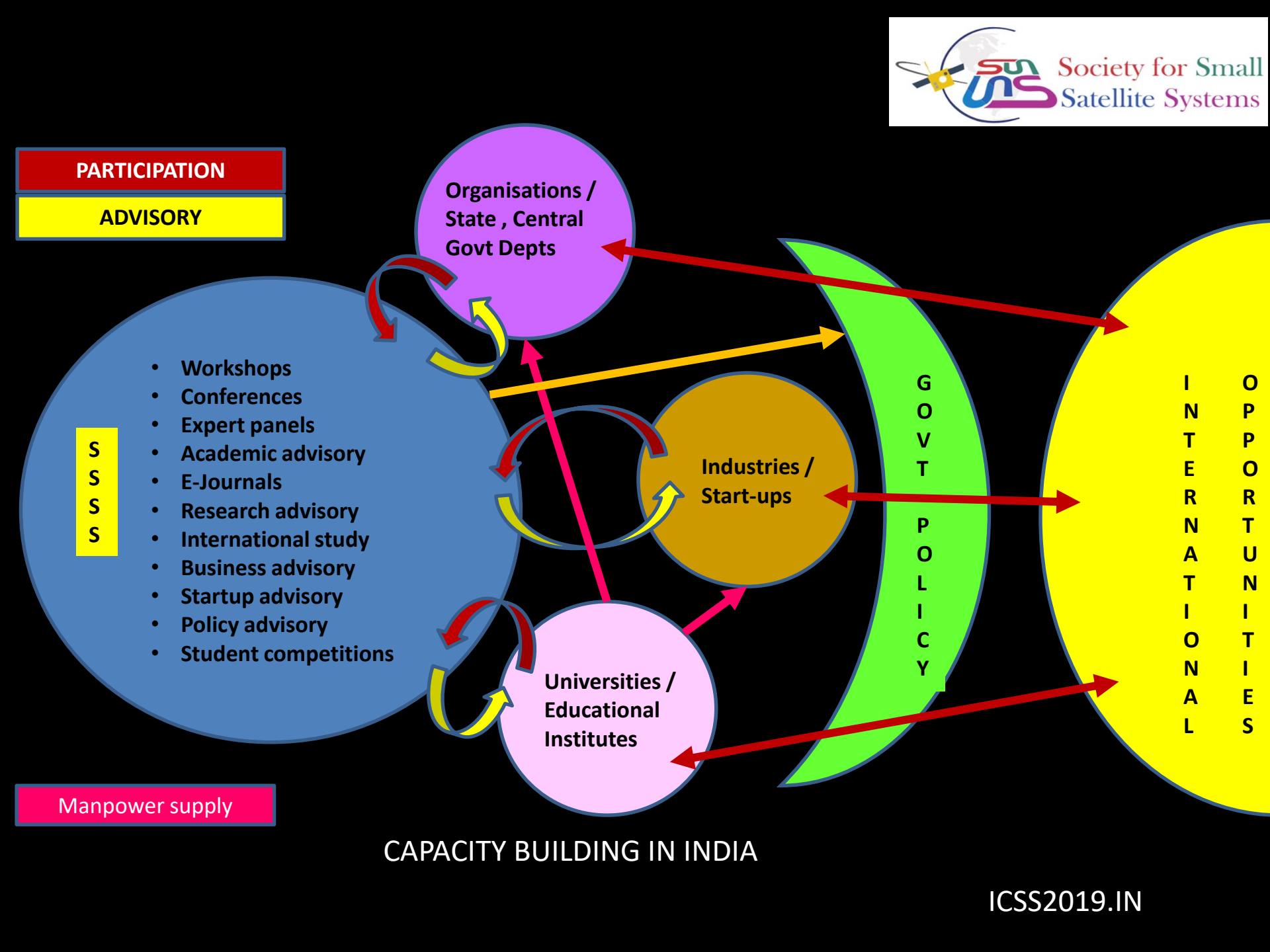
Good points and advantages of small satellite constellations

- Constellation serves high temporal freq applications
- Participative collaborative missions
- Wide spectrum of applications
- Easier access to space for individual countries
- Capacity building in the countries
- Opening up for many research areas
- More job opportunities in all participating countries

Some of important Points to be taken care

- Quality and reliability
- More spacecraft autonomy designs
- Ready Product delivery (80%)
- Direct to mobile
- Data sharing
- Freedom within regulations
- Equal opportunities to all countries (with hand holding)
- Deorbiting rules
- Openness of purpose

- SS PROVIDES CHALLENGES AND OPPORTUNITIES TO STUDENTS


Society for Small Satellite Systems
PARTICIPATION
ADVISORY
Organisations / State , Central Govt Depts
S S S S
Workshops
Conferences
Expert panels
Academic advisory
E-Journals
Research advisory
International study
Business advisory
Startup advisory
Policy advisory
Student competitions
Industries / Start-ups
Universities / Educational Institutes
GOVT POLICY
INTERNATIONAL OPPORTUNITIES
Manpower supply
CAPACITY BUILDING IN INDIA
ICSS2019.IN

SMALL SATELLITES CONCLUSION

- SMALL SATELLITES : MINIATURISATION WITH A MEANING
- **FAILURES ARE POSITIVE FEEDBACK – LEARN AND CORRECT (ALL BIG SPACE ORGANISATIONS FOLLOWED THIS PATH)**
- **GOOD DOCUMENTATION IS ESSENTIAL – IT SHOWS WHERE TO CORRECT**
- **MISSION GOAL DEFINES SYSTEM**
- **GOAL CAN BE SOCIETAL APPLICATION, TECHNOLOGY DEVELOPMENT OR KNOWLEDGE EXPANSION**
- **SYSTEMS ENGG IS THE PROCESS TO MAKE THE SYSTEM**
- **NEVER LOSE SIGHT OF THE GOAL**
- DESIGN STURDY TO MEET SURVIVAL REQ
- DESIGN AS A BUS WITH MODULARITY, ACESSABILITY AND ADOPTABILITY
- SIMPLICITY IS BEST ENG
- RELIABILITY IS RESPECTED AND IT PROTECTS GOAL

SMALL SATELLITES -- CONCLUSION (Con

- STANDARDISATION WITH SCALING
- SS TECHNOLOGIES : GREAT CHALLENGES AND RESEARCH OPPORTUNITIES
- NANO SATS ENTERING OPERATIONAL AREA: REQUIRES STRONG QUALITY ASSURANCE
- AVOIDING TESTS ENSURES RISK
- GO AHEAD AGAINST ODDS – THESE ARE NATURAL FOR INVENTIONS
- FIX LAUNCHER(S) BEFORE STARTING DESIGN
- A SATELLITE BUS MEETS DIFFERENT MISSIONS WITH LEAST ADJUSTMENTS
- **SATELLITE BUSSES** ARE USEFUL FOR CONSTELLATIONS
- SS PROVIDES CHALLENGES AND OPPORTUNITIES TO STUDENTS
- EXPERIENCE GIVES BOOKS – BOOKS DON'T GIVE EXPERIENCE -- EXPERIENCE IS THE REAL KNOWLEDGE
- COLLBARATIONS ARE A MUST FOR CONSTELLATIONS

STELLITE CONSTELLATIONS : WITH ALL AND FOR ALL

WORLD IS NO MORE GLOBAL VILLAGE

IT IS A GLOBAL ROOM

THANKS TO UNOOSA FOR THE OPPORTUNITY
THANKS TO ALL OF YOU FOR GREAT PRESENCE
THANKS TO ORGANISERS

THANKS FOR ATTENTION

I ACKNOWLEDGE ISRO AND THE YOUNG TEAMS FOR THEIR SUPPORT IN CREATING SMALL SATELLITE BUSSES AND MISSIONS
I ACKNOWLEDGE THE VELTECH UNIVERSITY FOR ENCOURAGING AND SUPPORTING THE CAUSE OF SMALL SATELLITES
I ACKNOWLEDGE SSSS EC AND MEMBERS FOR THEIR ENCOURAGEMENT
I LOVINGLY ACKNOWLEDGE MY WIFE Dr RAMAVANI AND CHILDREN FOR GREAT SUPPORT IN MY LIFE AND CAREER

Raghava Murthy V A Dantu
raghavdva2@gmail.com